The Central kpc of Starbursts and AGN
ASP Conference Series, Vol. xxx, 2001
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HI absorption from the central kpc of radio galaxies: effect of orientation or interstellar medium?

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Abstract. We present a summary of recent studies of HI absorption in radio galaxies. The results show how the absorption can be due to a variety of phenomena and how they can help us in understanding more of what is happening in and around AGNs.

1. Introduction

The study of neutral hydrogen is one of the tools we can use to investigate the cool diffuse ISM in the central regions of AGNs and Starbursts. This gas component is believed to be connected to the fuelling and the obscuration of the "central engine", both important aspects of the study of the AGNs. The infall of gas (possibly fuelling the AGN) can also trigger a central starburst and give, perhaps, some clues of the AGN/starburst connection. Observations of HI absorption against radio loud AGNs have been carried out for many years as soon as it was recognised that the radio activity might be associated with the presence of cold gas (see e.g. Gunn 1979). More recent observations - more sensitive and of higher resolution - have shown how atomic gas can actually probe a variety of phenomena in the nuclear regions around radio loud AGN. To illustrate this, I will briefly summarise some of the results we have recently obtained in the study of HI absorption.

2. Thin disks in FRI radio galaxies?

Obscuration is one of the main ingredients in the unification schemes of AGNs. Thick tori are believed to be present in powerful radio galaxies and a combination of beaming and obscuration would explain the lack of broad optical emission lines in some of these galaxies. From recent studies (both observational e.g. Cygnus A, Conway 1998, and theoretical, Maloney et al. 1996), it is now clear that under certain conditions, the torus does not have to be solely molecular, as original predicted, but atomic gas can be present also in the very central regions of AGN, e.g. in the form of an obscuring disk/torus-like structure. For low power radio galaxies (i.e. Fanaroff-Riley type I), however, the situation is not so clear yet. Using HST images, Chiaberge et al. (1999) found that unresolved optical cores are commonly present in these radio galaxies. A strong correlation is found between the fluxes of the optical and the radio core, arguing for a common non-thermal origin (synchrotron emission from the relativistic jet). All this suggests that the *standard pc-scale geometrically thick torus is not present in these low-luminosity radio galaxies*. Thin disks-like structures have been observed in HI absorption in the case of NGC 4261 (van Langevelde et al. 2000) and Hydra A (Taylor 1996). Thus, the study of HI absorption has the potential to help us to answer the main question whether the FRI/FRII dichotomy reflects fundamental differences in the innermost structure of the central engine.

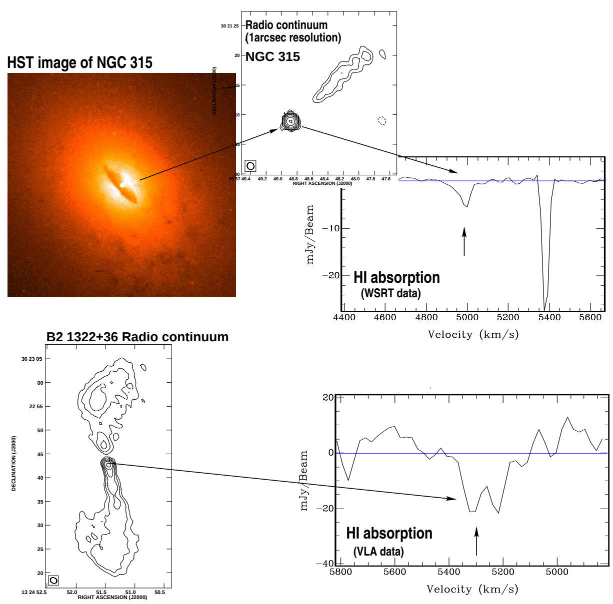

Figure 1. HI absorption detected with the WSRT and the VLA against the core of two radio galaxies: NGC 315 and B2 1322+36

In a study of HI absorption of a complete sample of FRI radio galaxies (Morganti et al. 2001), we have found a low rate of detections. Only one of the 10 FRI galaxies observed were detected in HI absorption. To first order, this result is consistent with the idea that the cores of these radio galaxies are

relatively unobscured. To investigate this idea in more detail, we have studied HI absorption (with the VLA and the WSRT) in an other sample of radio galaxies for which information from HST images about the presence of optical cores and nuclear dusty disks/lanes are available (Capetti et al. 2000, de Ruiter et al. these proceedings). Thus, the HI observations *aim to correlate the presence (or absence) of HI absorption with the optical characteristics*. We find HI absorption in 4 of the 9 B2 galaxies observed. In particular, absorption was detected in the two galaxies in the sample that have dust disks/lanes and *no* optical cores (B2 1322+36 and B2 1350+31 (3C293)). In these cases, the column density of the absorption is quite high ($> 10^{21}$ cm^{-2} for $T_{\rm spin} = 100$ K) and the derived optical extinction A_B (between 1 and 2 magnitudes) is such that it can, indeed, produce the obscuration of the optical cores. In the other two cases (B2 0055+30 (NGC 315) and B2 1346+26), HI absorption has been detected despite the presence of optical cores. The column density derived from the detected absorption is, however, much lower ($\sim 10^{20}$ cm^{-2} for $T_{\rm spin} = 100$ K) and the derived extinction is of the order of only a fraction of a magnitude. The detected HI absorption could be part (the innermost?) of the dusty disks seen with HST (see the one observed in NGC 315 shown in Fig. 1) but the resolution of the VLA observations do not give any spatial information (i.e. the HI absorption lines are all detected against the unresolved core). Only VLBI observations will be able to tell us about the real distribution and kinematics of the neutral gas. In particular, if no large obscuration is found against the very central core also from the HI absorption, the lack or weakness of broad optical lines in FRI radio galaxies compared to other AGN will have to be explained by something other than obscuration effects. So far, broad lines have been *tentatively* found only in very few cases of FRI radio galaxies.

3. Interpreting the HI absorption: the problem of the redshift

An important issue for understanding the origin of the H I absorption is how the systemic velocity of the galaxy compares with the velocity of the H I. It was already pointed out by Mirabel (1989) how the systemic velocities derived from emission lines can be both uncertain and biased by motions of the emitting gas. This is nicely illustrated by our results on the compact radio galaxy PKS 1549-79 (see Tadhunter et al. 2001 for details). At radio wavelengths, PKS 1549–79 is a compact (the size is 150 mas, about 350 pc for $H_\circ = 50$ km s^{-1}Mpc^{-1} and $q_\circ = 0$) flat spectrum source with a one-sided jet. The radio structure indicates that the radio jet axis is aligned with our line of sight. Despite this, HI absorption was detected (optical depth ~ 2 %) and the profile is shown in Fig. 2. In the optical, the most surprising characteristics is that *two redshift systems* were found from the emission lines: the higher ionisation lines (e.g. [OIII]5007Å) have a significant lower redshift (velocity difference of $\Delta v = 600$ km s^{-1}, see Fig. 2) than the low ionisation lines (e.g. [OII]3727Å). *The velocity derived from the low ionisation lines is consistent with the one derived from the H I. No evidence for broad permitted lines* has been found, quite unusual for a flat spectrum radio source and the high ionisation forbidden lines are also unusually broad (1345 km s^{-1}).

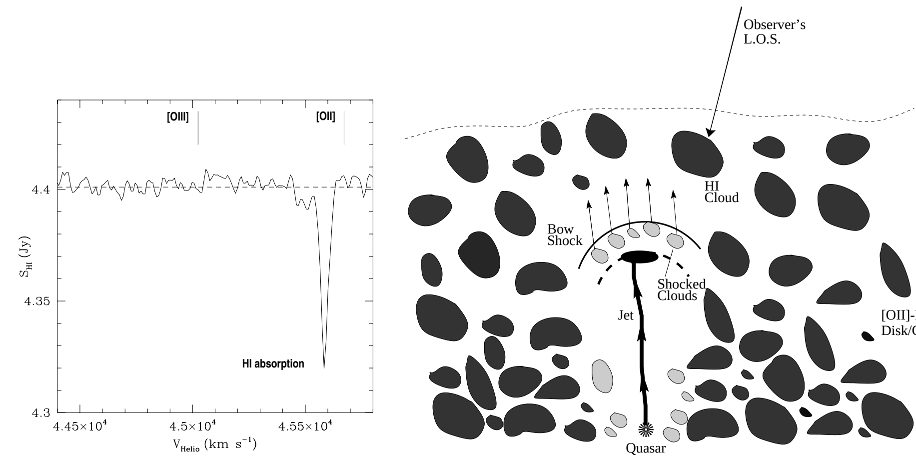

Figure 2. *(Left)* HI absorption profile obtained with the Australian LBA of PKS 1549-79 with superimposed the velocity of the ionised gas. *(Right)* Cartoon of the possible distribution of the various components (see text for details).

All this suggests that in PKS 1549–79 the high ionisation lines are formed in a region close to the central AGN, which is undergoing outflow because of interactions, e.g., with the radio jet, while the low ionisation lines and the HI absorption come from an obscuring region at larger distance and not so disturbed kinematically. Moreover, PKS 1549–79 is one of the few known radio galaxies at low redshift which shows a strong component from a young stellar population (see §5 for some more on these galaxies), and strong far-IR emission. Thus, it is likely that it is a *young* source where the nucleus is surrounded by a cocoon of material left over from the events which triggered the nuclear activity. As the radio source evolves, any obscuring material along the jet axis is likely to be swept aside by, e.g., jet-cloud interactions. In Fig. 2 is shown a schematic diagram of the various components. A major implication of this work is that the simplest version of the unified schemes *may not always hold for young, compact radio sources*. The possibility that the medium around (i.e. in the form of a starburst component) could affect the way we see the AGN especially at optical wavelengths has been recently pointed out also by the work of Levenson et al. (these proceedings) in the case of the Starburst/Seyfert-1 galaxy NGC 6221.

4. Infall and outflow

In previous studies, the HI absorption was mainly found either at the systemic velocity or redshifted compared to it (van Gorkom et al. 1990). As a result of the HI studies we have done so far, we found both redshifted and blueshifted (with respect to the systemic velocity) cases of HI absorption. However, it is clear from the above discussion that, in general, accurate redshifts are needed before drawing any strong conclusion.

At present, there are only a few cases of clearly redshifted HI absorption where a cloud falling into the nucleus could be the cause for the absorption.

One of these cases is NGC 315. As evident from Fig. 1, two HI absorption systems are detected: a newly discovered (broad) HI absorption at the systemic velocity and a well known deep and very narrow component (Dressel et al. 1983) 500 km/s redshifted compared to the systemic velocity. Similar double HI absorptions have been found only in NGC 1275 and 4C 31.04. The real cause of the redshifted absorption is still unclear. Despite our very sensitive HI observation done with the WSRT, we detect this absorption *only* against the nucleus (no similar absorption at the 5% optical depth limit is seen against, e.g., the radio jet). This may mean that is due to a cloud physically associated with the nuclear regions, i.e. a cloud close to the nucleus, falling into it and "feeding" the AGN.

In some cases, the HI absorption seems to come from gas situated around the radio lobes affected by the interaction with the radio plasma (i.e. outflow). The best example is the Seyfert galaxy IC 5063. In this galaxy, very broad, blue-shifted (up to $\sim$ 700 km s^{-1}) HI absorption has been detected (Oosterloo et al. 2000) at the location of the western radio hot spot at about 700 pc from the nucleus. Such velocities are much too high to be explained by gravitational motion and the only viable explanation is that at the location of the hot spot the radio jet is hitting the ISM of the galaxy, pushing out the ISM at these high velocities. An other example is the compact radio galaxy PKS 1814-63. In this galaxy the HI absorption is observed against the entire radio emission (Morganti et al. 2000). Most of the HI absorption (with optical depth as deep as 30%) is blueshifted compared to the systemic velocity of the galaxy (at least if we rely on the redshift available so far). Thus, this component could be associated with extended gas, possibly surrounding the lobes and perhaps interacting/expanding with them.

5. Starburst radio galaxies

A small fraction of powerful radio galaxies shows strong optical/UV starburst activity as well as strong far-IR emission (Wills et al. 2001 and these proceedings). For these objects it is generally assumed that the far-IR excess represents reprocessed starlight. These powerful radio galaxies are potentially valuable probes of the formation and evolution of radio galaxies and QSRs, as well as early-type galaxies in general.

Although the statistics is limited, we found a tendency for the far-IR bright, starbursting radio galaxies to be detected in HI absorption. Apart from the two objects mentioned above (PKS 1549-79 and 4C12.50) we have detected HI absorption in 3C459 and B2 0648+27 while other cases were already known from the literature (3C321 and 3C433 Mirabel 1989, 1990). Thus, the rich ISM likely to be present in these galaxies, as suggested by the strong far-IR emission and the star formation, could have some relation with the detection of HI absorption. In some of these cases, HI absorption can be due to a nuclear torus/disk. An important part of the process of formation of radio galaxies described above would be the formation of a self-graviting gas disk that would bring the gas into the nucleus and fuel the AGN. Evidence for a disk has been found in some ultraluminous infrared galaxies (ULIG) and a connection between ULIGs and powerful radio galaxies with starburst activity and far-IR emission could exist in

that the latter could represent the first evolutionary result of ULIG. However, in other cases, gas in turbulent motion or tails of gas remnant from the formation of the galaxy itself could have a role in producing the absorption. This could be the case in PKS 1549-79, as described above, but also in other objects (like 3C433) where the absorption is seen against one of the radio lobes instead of the nucleus.

6. Summary

We have presented some results from studies of HI absorption in radio galaxies. We have found that the absorption can be due to a variety of phenomena. In observed the FRI radio galaxies, the detected absorption is likely to be due to circumnuclear disk/torus that could be geometrically thin, consistent with what derived from HST data. However, many other situations have been found: extreme outflows, more quiescent absorbing clouds, and structures likely to be associated with a merger remnant. In particular, we find a tendency for radio galaxies with a strong component of young stellar population and far-IR emission to show HI absorption. Thus, HI absorption gives a powerful tool to probe different phenomena in and around radio loud AGNs.

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